The Montana Department of Environmental Quality Sediment Assessment Method: Considerations, Physical and Biological Parameters, and Decision Making

Final

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACRONYMS

Acronym	Definition
DEQ	Department of Environmental Quality (Montana)
EPA	Environmental Protection Agency (US)
GPS	Global Positioning System
MCA	Montana Codes Annotated
MFISH	Montana Fish Wildlife and Parks Montana Fisheries Information
PIBO	PACFISH/INFISH Biological Opinion
QAPP	Quality Assurance Project Plan
RPD	Residual pool depth
RSI	Riffle Stability Index
SRS	Site Response Section
TMDL	Total Maximum Daily Load
USDA	United States Department of Agriculture

1.0 INTRODUCTION

Excess sediment can be detrimental to the biotic communities within a waterbody. Increasing sediment levels can lead to a decrease in periphyton biomass (Yamada and Nakamura, 2002) as well as a decrease in macroinvertebrate density and diversity (Waters, 1995) and a shift in macroinvertebrate community toward burrowing taxa (Suttle, et al., 2004). Effects on salmonids include impaired growth and survival of juveniles (Suttle, et al., 2004), reduced redd escapement by fry (Fudge, et al., 2008), and decreased spawning success (Fraley and Weaver, 1993; Tappel and Bjornn, 1983; Reiser and White, 1988). In addition to causing a reduction in habitat quality, excess sediment (fine or coarse) filling riffles and pools can reduce the quantity of habitat available for organisms during part or all of their life cycle.

The Montana narrative standard for sediment states: "No increases are allowed above naturally occurring concentrations of sediment or suspended sediment (except as permitted in 75-5-318, MCA), settleable solids, oils, or floating solids, which will or are likely to create a nuisance or render the waters harmful, detrimental, or injurious to public health, recreation, safety, welfare, livestock, wild animals, birds, fish, or other wildlife" (17.30.623 (f)). Thus, defining what is natural within a system and demonstrating harm to the aquatic biota as a result of increased sediment are integral to determining whether or not a waterbody is impaired by sediment. Sediment can cause harm through multiple routes of exposure, and although high percent fines can limit salmonid embryo survival, this could be the natural condition for a waterbody. Also, high percent fines may not suppress adult salmonid populations if some other factor such as overwintering (Chapman, 1988) or rearing (Magee, et al., 1996) habitat is limiting.

In addition, if a stream is impacted by sediment, different locations within the stream may be affected differently (Lisle, 1989). Identifying the natural sediment condition within a waterbody as well as demonstrating that sediment is proving harmful to aquatic life among the physical, chemical, and biological complexity present in aquatic systems is not a simple task. Despite this challenge, the development of well-planned sampling schemes and collection of biologically relevant and statistically rigorous data can help streamline and simplify this process.

2.0 PURPOSE

The purpose of this paper is to describe techniques to be used when assessing a waterbody for sediment impairment. This is part of the development of an assessment translator that will streamline the decision making process with regards to sediment condition and the effects of sediment on the "aquatic life/fishes" beneficial use. The translator will require specific data to be collected and input in order for the Montana Department of Environmental Quality (DEQ) to make consistent sediment impairment decisions. The methods described are supported by peer-reviewed literature and represent what we believe to be the best currently available options for collecting reproducible and statistically rigorous data with limited bias. The following methods are designed to answer specific questions related to the instream sediment condition. Although this paper represents our best efforts to address sediment impairment in most western Montana streams, it is by no means an end-all approach to making such determinations.

The following assessment method will be performed to assess the effects of "sedimentation/siltation" and "bedload solids" on mountain and transitional streams in western Montana. When this method

demonstrates that these streams are not meeting the standard for sedimentation/siltation and bedload solids, they will be placed on the 303(d) list.

When performing an assessment, water quality data should be collected consistently to allow for comparisons between data sets (Roper, et al., 2010). Collecting data in a repeatable manner will benefit DEQ when examining the status of a waterbody over time. Comparability of data collected by the various groups internal to the Water Quality Planning Bureau as well as external entities (e.g. Watershed Management Section (DEQ), United States Forest Service) will result in more robust data sets and prevent unnecessary sampling. The assessment method described herein has been developed with this in mind.

3.0 DATA COLLECTION

The streams (or the segment) being assessed with this assessment method must be contained within the Northern Rockies, Middle Rockies, Canadian Rockies, or Idaho Batholith level III ecoregions (**Figure 1**). Additional constraints to this protocol include that streams must be perennial or intermittent, and Strahler order ≤ 4 (Strahler, 1957b; 1957a). In addition, this assessment method will only be used on Strahler order 1 streams when deemed appropriate. These conditions have been applied to the method recognizing that the sediment regimes of mountain streams in western Montana are vastly different from those of large rivers and eastern Montana prairie streams. These situations present their own unique challenges when it comes to identifying routes of harm such as scale for large rivers and turbidity, high summer water temperature, and a tolerant ichthyofauna for eastern Montana prairie streams. Sediment assessment protocols that address large rivers and eastern Montana prairie streams may be developed by DEQ in the future.

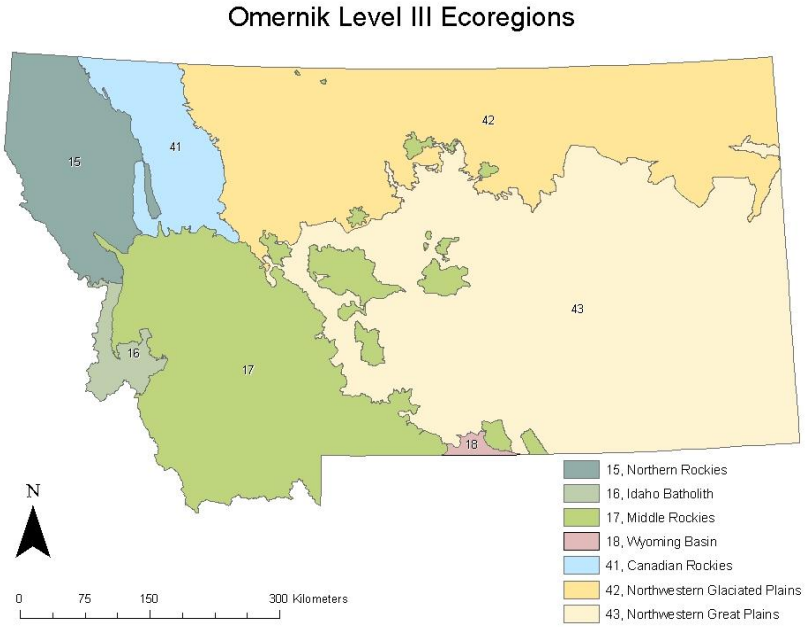


Figure 1. Level III ecoregions in Montana (Woods, et al., 2002)(Woods et al. 2002).
The assessment method within this document will be applied only to waterbodies within ecoregions 15, 16, 17, and 41.

When developing an assessment method, it is important to understand the linkage between the parameter of concern and the potential impacts to the use of concern, in this case the aquatic life/fishes beneficial use. This assessment method applies a weight of evidence approach utilizing environmental parameters recognized to cause harm (e.g., reduced survival, community shift, use of suboptimal habitat) at a certain level or concentration. The biological aspect relied upon to infer physical measures that can relate harm to the aquatic life/fishes beneficial use relative to sediment is fish. This decision was made due to the large number of peer-reviewed studies (laboratory and field-based) linking fine sediment to reduced spawning and rearing and habitat loss to aggradation. In addition we found that studies for other biological communities that quantified sediment concentrations to harm generally used similar physical measurements as in those for fish.

The data collected from a given stream will be compared to that of expected "reference condition" (Suplee, et al., 2005; Stoddard, et al., 2006) for that particular stream in the weight of evidence approach. Reference data used may include data collected from a reference reach within a stream, external reference reaches, or literature values for a particular stream type. This method has been used by Kershner et al. (2004b) and Kershner and Roper (2010) to distinguish between reference and managed watersheds in the western United States. Although there is literature supporting the development of thresholds for fine sediment impacts to aquatic organisms (Bryce, et al., 2010; 2008; Paul, et al., 2008; Kaller and Hartman, 2004), DEQ has opted to not take the threshold approach at this time. The inherent variability within watersheds can create problems when thresholds are applied to habitat metrics (Al-Chokhachy, et al., 2010; Kershner and Roper, 2010). This could lead to placing streams on the 303(d) list that do not belong there or vice versa. Collection of data for both reference streams and streams to be assessed (target) using this method will create a robust dataset that can facilitate the development of fine sediment thresholds if deemed appropriate by DEQ in the future (see Cormier et al. (2008) and USEPA (2006) for examples of how this may be done).

In making impairment determinations, there is a chance of making the following two types of errors:

Type 1: Identifying a stream segment as impaired for sediment when in reality, it is fully supporting the aquatic life/fishes beneficial use.

Type 2: Identifying a stream segment as fully supporting when in actuality, sediment is harming one or more biological community.

No single sediment tool exists to fully describe all types of harm to aquatic life in all surface water systems in Montana. In an effort to reduce incidence of type 1 and type 2 errors, we have incorporated the following into our assessment method:

- Use of a multiple reference approach for a given parameter when possible to help evaluate a stream's use support capabilities relative to a given parameter;
- Evaluation of multiple parameters to determine impairment so that an error in evaluating one parameter is less likely to result in an error in making an impairment determination;
- Identification of linkage between instream condition and indentified sources, either existing or historical;
- Appropriate planning to ensure collection of sufficient data to detect differences between target and reference populations;
- The opportunity to improve upon data collection and analysis methods to help ensure program consistency and overall quality assurance.

Because we recognize that no single parameter will accurately indicate impairment due to fine and/or coarse sediment (or a lack thereof), five different parameters will be collected that will aid in describing routes of harm caused by sediment (see **Appendix B** for the field methods). The results of no single parameter will outweigh the results of any other. In addition, this assessment method considers reference condition and uses stratification to make comparisons between target streams and similar reference sites. When physical parameters indicate potential impairment, biological parameters will be analyzed to determine if the physical deviation from reference is manifesting in biological disturbance. Finally, in situations where the measurement of physical parameters is severely limited (e.g., there are no pools or riffles), analysis of those that are collected will take place and the assessment decision will be supplemented by the best professional judgment of the assessor, DEQ management, and when possible, the input of a local biologist.

The foundation of data collection for this assessment method is the appropriate identification of morphological habitat units within a stream. Agreement between observers for habitat identification can be quite low when compared to random assignment and reducing the number of habitat types to be identified maximizes the likelihood of observer agreement (Poole, et al., 1997). As a result, only two habitat units (pools and riffles) will be identified (**Figure 2**).

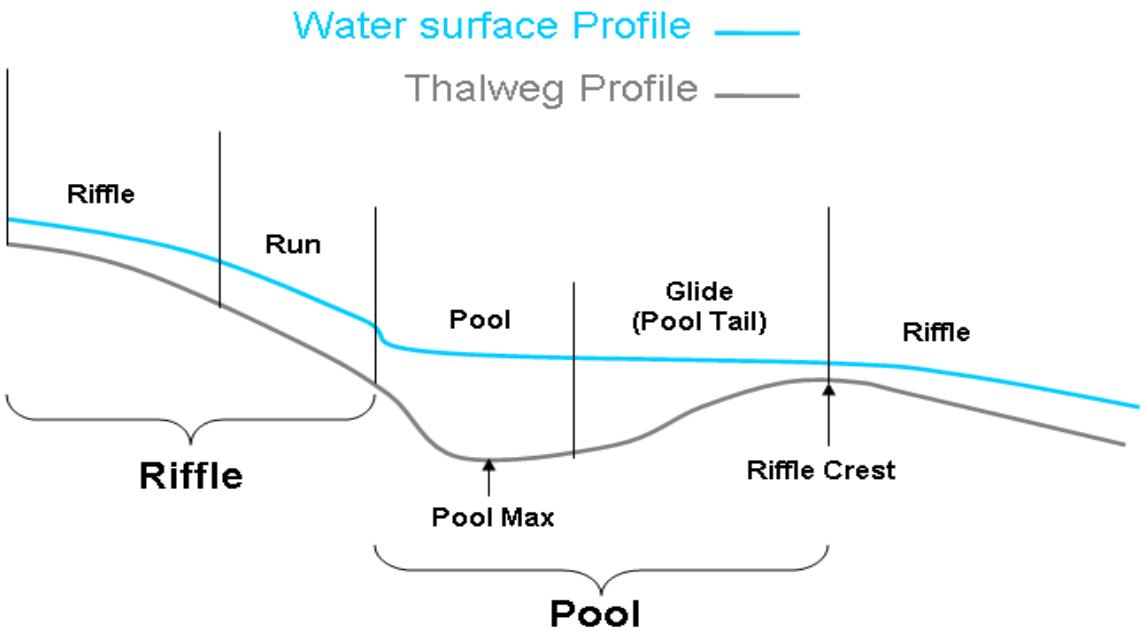


Figure 2. Longitudinal profile of a stream bottom along the thalweg and the water surface.
For this assessment, run habitat will be considered riffle, and glide habitat will be considered pool.

To determine fine sediment impairment, riffle and pool-tail percent fines will be measured. These parameters both address surface fines within a stream. For the purpose of this document, percent fines are defined as the percentage of sampled substrate material that is less than 6 mm, less than 5.7 mm and less than 2 mm, as these are values supported throughout the literature as having effects on aquatic biota (Fraley and Weaver, 1993; Suttle, et al., 2004; Phillips, et al., 1975; Edwards, et al., 2007; Shepard, et al., 1984; Yamada and Nakamura, 2002). If deemed necessary by the assessor, larger or finer size fractions (e.g. 9.5 mm, 0.85 mm (Tappel and Bjornn, 1983)) may also be examined. The goal of measuring percent fines is to evaluate the quality of available spawning habitat within a stream.

A more robust version of the Wolman pebble count (Wolman, 1954) will be used to sample percent surface fines than has been used in the past by DEQ. This method is designed to reduce sampling bias, improve representation of the substrate present, and improve data comparability and reproducibility both within and between streams. A second means of measuring percent surface fines, the grid toss, will be used in pool tails exclusively (Kershner, et al., 2004a; Heitke, et al., 2010).

To further address fine sediment issues as well as consider possible aggradation and coarse sediment supply, residual pool depth (Lisle, 1987) and pool frequency will be measured. Measuring changes in pool structure are important as pools serve as habitat for a variety of aquatic organisms (Muhlfeld and Bennett, 2001; Bisson, et al., 1982; Roni, 2002; Sullivan, et al., 1987; Lewis, 1969). Pools are especially important for fish as winter habitat (Harper and Farag, 2004; Heifetz, et al., 1986; Jakober, et al., 2000) and refuge from thermal stress (Baird and Krueger, 2003; Matthews, et al., 1994; Nielsen, et al., 1994) and water velocity (Bonneau, 1998; Bunt, et al., 1999). Increased sediment in a system can cause a reduction in pool size, depth, and number, and an increase in distance from one pool to the next (Lisle, 1982; Buffington, et al., 2002). Aggradation due to coarse sediment supply can lead to streams becoming intermittent with stranded pools that provide limited fish habitat (May and Lee, 2004). These resulting changes have ramifications for aquatic populations' stability, persistence, and ability to recover from disturbance (Lonzarich, et al., 2004). Measuring pool parameters will help DEQ determine the amount of habitat available for juvenile rearing and adult fishes.

If it is deemed that a single season of sampling is insufficient to make an impairment determination with regards to sediment, data collection of the core parameters during a second season must take place and the collection of supplementary sediment parameters may be necessary. Methods for measuring Riffle Stability Index (RSI; (Kappesser, 2002), subsurface fines (McNeil and Ahnell, 1964; Young, et al., 1991) intragravel dissolved oxygen (which may be affected by the percent fines (Kondolf, 2000; Maret, et al., 1993)), and residual pool volume (V*; the fraction of pool volume filled with fine sediment; (Lisle and Hilton, 1992; 1991) are discussed in **Appendix A**.

The following considerations and parameters apply when sediment sources are identified during a risk assessment, impairment needs to be reassessed, and/or when describing the natural condition of reference waterbodies.

3.1 DATA COLLECTION REQUIREMENTS

All physical parameters should be collected under base flow conditions to limit the likelihood of misidentifying a feature due to flow conditions (e.g. identifying a feature as a run at high or moderate flows when it would be considered a pool at base flow). Physical data must also be collected from a minimum of one representative site per stream segment for assessment to take place. Multiple sites may be sampled, but should only be combined when deemed appropriate by the assessor. For example, if a stream has one site that has a slope > 4% in the mountains and one with a slope < 1% in the valley it is likely inappropriate to combine the two samples when comparing their riffle percent fines values to reference. What determines one site to be similar to or distinct from another is ultimately the decision of the assessor and may be different depending on the stream's ecoregion, historical land use, etc. If a stream is relatively homogenous, then one site must be sampled per each five miles of stream. Sampling of additional sites may occur (and is strongly encouraged); especially when it is suspected or known that there are sediment sources along the stream. Although sampling a single site on a stream is not ideal, the sampling methods have been designed to produce a representative description of the condition of a given stream reach. In situations where cost, time, access, etc., limit the number of sites that can be

sampled, meeting the minimum requirements will afford DEQ the confidence to make a defendable impairment decision.

Biological data must consist of a minimum of two independent macroinvertebrate and two independent periphyton samples for each type of site with physical data collected. These samples must be collected during the time period for which metrics were developed. The samples may be collected from the same site during a single year (as long as they meet temporal independence requirements), from multiple sites within a year, over multiple years, or any combination of these. The samples do not need to be collected from the same location as the physical data as long as all data being examined was collected from a location with the same type of stream attributes as the physical data.

3.2 SITE SELECTION

Sampling locations will be chosen prior to the beginning of fieldwork. Selection of sites will be based on the results of a risk-based analysis for the waterbody (the methods for which are currently in development) and the best professional judgment of the assessor. Site locations may be adjusted in the field if the assessor determines the preselected site to be unsuitable or less appropriate for the assessment than another location.

A key component to the determination of sediment impairment is that sediment levels must be above natural. For this to occur in a waterbody, there must be anthropogenic sources. The sample scheme in this assessment method is based upon risk analysis and reach segregation. This should lead the assessor to bracket sources with sites and track instream conditions across land use changes. When collecting and analyzing data related to the sediment condition of a waterbody, the question, “Does this measure show a linkage between the source and the impact the source is creating?” must continuously be considered. This is an important concept because a waterbody could naturally have high levels of fine sediment due to inherent characteristics and have potential anthropogenic sources that do not actually contribute to the sediment load above the natural variability. An example of this consideration might be a stream with underlying granitic geology that naturally has a high level of fine sediment 2 to 6 mm. This waterbody may also have locations where culvert crossings are a possible input of fines < 2 mm. If pebble counts below the culverts indicate that there are 50% fines 6 to 2 mm, but 0% fines < 2 mm, then it becomes very difficult (if at all possible) to say that the crossings can be linked to the high amount of fines in the stream. If, on the other hand, pebble counts indicated 10% fines < 2mm below the culvert and 1% fines above, an assessor could make the argument that the culvert has caused the < 2 mm fraction to be above natural for that stream. Linking anthropogenic sources of sediment to measureable physical parameters is an important step in determining the natural condition of a waterbody. Sites will be selected to address potential effects of anthropogenic sediment sources.

3.3 SITE LENGTH

The goal in defining the sample frame from which data will be collected is to gain a representative snapshot of the stream segment being considered in the assessment. To ensure data representativeness, sampled reaches must be relatively homogenous (i.e., the reach is not a transition between two channel types). The length of a stream site that will be sufficient to effectively describe habitats can vary depending on the heterogeneity of the stream. Although different programs use different distances for their site length (e.g. EPA’s EMAP uses 40 times wetted width (Kaufmann, et al., 1999; Rosgen, 1996), Rosgen (1996) uses 20 times bankfull width), 20 times the wetted width is generally the minimum distance used (Fitzpatrick, et al., 1998; Simonson, et al., 1994). Leopold et al.

(1964) determined that riffle/pool sequences are typically 5-7 bankfull widths in length and Keller and Melhorn (1973) reported riffle/pool sequences to be 3-9 bankfull widths. Using site lengths at least 20 times bankfull means that sampling will likely take place over multiple meander wave-lengths and riffle-pool units, and will aid in determining averaged values for specific populations (e.g, riffles) that account for local effects (Bunte, et al., 2009). As a result, site length for sediment sampling will be a minimum of 20 times the bankfull width. This site length will be appropriate for a greater range of stream widths, can provide more rigor in statistical analysis (Simonson, et al., 1994), and will allow for a more reliable representation of residual pool parameters (Keim and Skaugset, 2002) than using a shorter site length. Using a site length 20 times the bankfull width equates well with the site length system used by DEQ TMDL (Total Maximum Daily Load) planners when verifying sediment impairment (Montana Department of Environmental Quality, 2006b). All sites will begin and end at the downstream extent of a habitat feature (riffle or pool).

3.4 PERMANENT SITES

Each sampling site will be georeferenced (downstream and upstream extent) to allow for future sampling of the same features within a site (Olsen, et al., 2005; Roper, et al., 2003; Roper, et al., 2002a). Permanent sampling sites will allow for analysis of change at given locations over time, comparisons of variability within and between sites, and provide a starting point for other groups to conduct sampling (TMDL data collection, annual monitoring by conservation districts, etc.). In addition to helping provide rigorous data for assessing impairment, using permanent sites will facilitate the development of trends through time and differing management regimes. Collection of data at permanent sites will be an asset when performing TMDL five-year reviews and reassessments of 303(d) listed waterbodies. When georeferencing sampling sites, GPS coordinates of both the lower and upper extents of the site, photos, and a written description of the location will be documented.

Collaboration between multiple entities within DEQ should take place to determine sampling locations that will be useful to involved groups. Agreement on site locations will help create a database for a waterbody that can be used and built upon by entities internal to DEQ and demonstrate potential changes through time.

3.5 TRAINING

To collect rigorous data that has limited bias and variability, comprehensive training of those collecting data will need to occur (Marcus, et al., 1995). Training will include how to classify habitat types (Roper and Scarnecchia, 1995) and objectively measure habitat parameters (Roper, et al., 2002b). Annual field training is required for all DEQ employees collecting data (Montana Department of Environmental Quality, 2005b). Training for this assessment method will include a manual containing clear instructions describing how to set up sampling sites, properly use measurement tools, and correctly record measurements. A two-phased training will be implemented; phase one will consist of a demonstration of habitat classification and parameter measurement and phase two will consist of the trainee(s) collecting data while being overseen by the trainer(s). Proper training of how to collect sediment data is essential to keeping data consistent over time and between collectors and must be part of making a defendable impairment decision.

3.6 PEBBLE COUNT

The sensitivity of riffles to increased sediment supply makes them a suitable location to sample for changes in substrate size distribution (Kappesser, 2002; Parker and Klingeman, 1982; Cover, et al., 2008; Dietrich, et al., 1989; Price and Leigh, 2006). In addition, riffles serve as a winter refuge for juvenile salmonids. Excess fine sediment can fill interstices and reduce the availability of this crucial habitat (Bjornn, et al., 1974). To sample the surface fines within riffles, a variation of the Wolman pebble count will be used (Wolman, 1954). The Wolman method is considered accurate and reproducible when sampling a single, homogeneous, population (e.g. one riffle; (Wolman, 1954; Kondolf, 1997). At least 100 particles will be sampled from each population (i.e. riffle) as this value has been deemed sufficient for the criteria previously stated (Mosley and Tindale, 1985; Wolman, 1954; Brush, 1961). The pebble count shall be performed within the bankfull channel(Heitke, et al., 2010). Although collecting particles in this way might skew results toward the size of sediments outside of the actual aquatic habitat at the time of sampling, Mebane (2001) demonstrated strong correlation between percent fines collected within the bankfull width and mactroinvertebrate parameters. To help address this potential bias, particles measured between the water's edge and the bankfull will be recorded as either fluvial (i.e., deposited by the relatively recent action of flowing water) or non-fluvial (i.e., older, established bank soil or substrate).

To reduce sampling bias, transects with set sampling locations and a sampling frame will be used to determine which particles to collect (Bunte and Abt, 2001a; Bunte and Abt, 2001b; Bunte, et al., 2009). In addition, a gravelometer will be used to measure the combined b, c -axis of each particle, as this helps to reduce operator error in measuring the particles and is more compatible with sieve data than using a ruler (Bunte and Abt, 2001a; Bunte and Abt, 2001b; Bunte, et al., 2009; Hey and Thorne, 1983; Roper, et al., 2010; Kondolf, 1997). Four individual riffles will be sampled per site, each with a 100 pebble count to yield a combined 400 particle riffle count, which according to Fripp and Diplas (1993) and Rice and Church (1996) yields the most efficient sampling results. If more than four riffles are present in a sampling site, four should be randomly selected to sample. This can be done by defining each riffle with a number and either using a random number table or writing the numbers on pieces of paper, and drawing four numbers out of a hat. If fewer than four riffles are present, a total of 400 particles will still be counted. The count will be evenly spread out among the riffles that are present using the same four-transect setup (e.g., if two riffles are present, each will have a 200 particle count). Multiple transects will be used to capture longitudinal variability present within a riffle. If the entire site is one riffle, then 16 transects will be evenly distributed throughout the site for sampling. If no riffles are present within the reach (e.g. the site is all pool due to beaver activity, etc.) the site will be moved to an alternate location. The determination of individual riffle populations to be sampled can be performed visually (Roper and Scarnecchia, 1995).

Within each riffle, four transects will be evenly distributed (from downstream to upstream) at 20, 40, 60, and 80% of the riffle length. Along each transect, 25 sampling locations will be evenly spaced within the bankfull width so that the distance between each is a maximum of 1/25 of the bankfull width. Bankfull width will be recorded for each pebble count transect. **Figure 3** provides a schematic of the riffle pebble count setup. Percent fine sediment less than 5.7 mm and less than 2 mm will be measured using this technique.

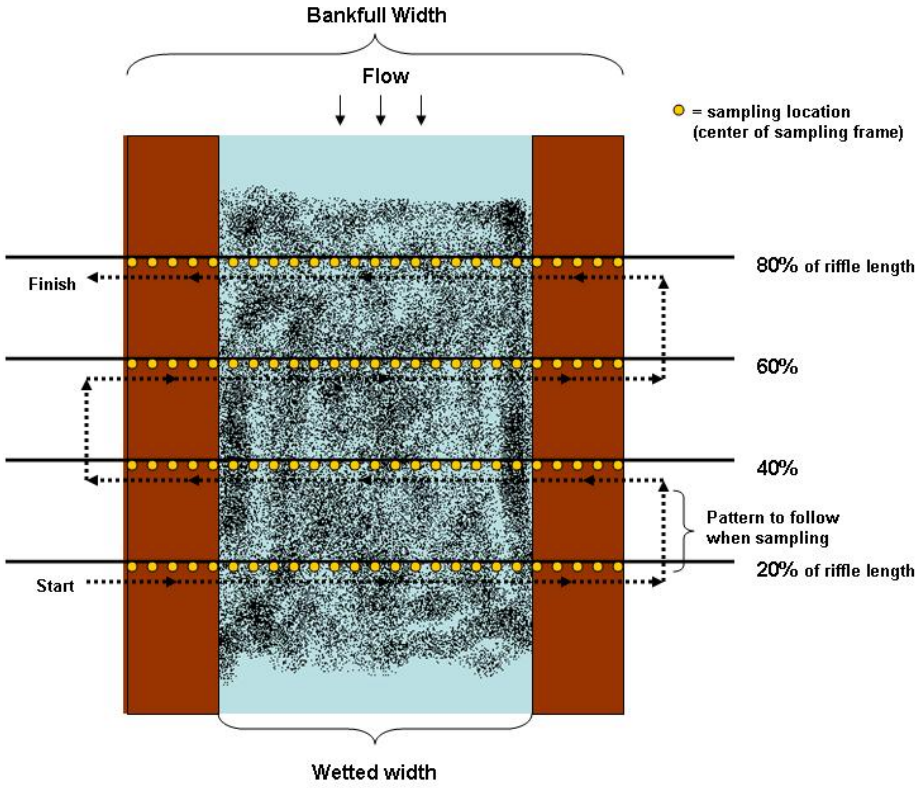
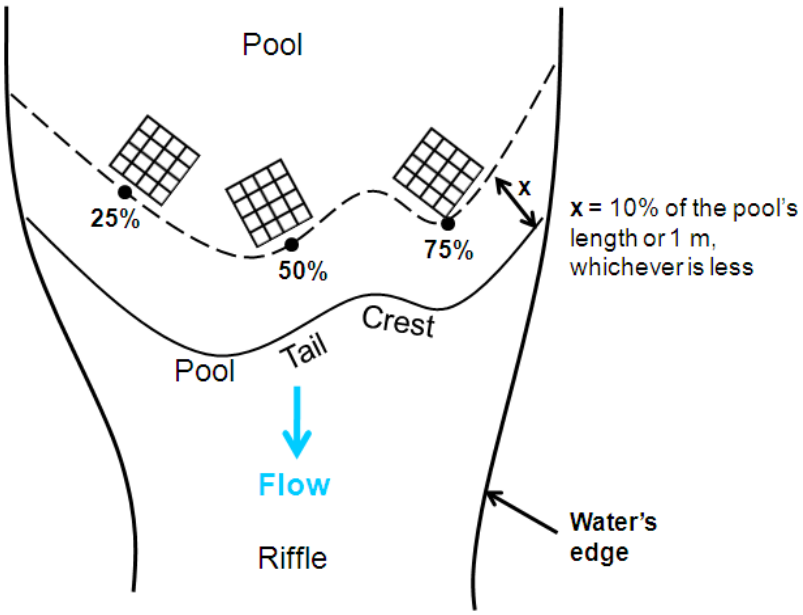


Figure 3. Setup for performing a riffle pebble count.

3.7 GRID TOSS

The grid toss will be performed to describe the substrate quality in the areas most likely used by salmonids for spawning. Salmonids generally can spawn in gravels with a D_{50} up to about 10% of their body length and tend to spawn in areas of streams where either downwelling or upwelling is present (Kondolf, 2000; Kondolf and Wolman, 1993). As a result, pool tails are a likely salmonid spawning location (Keller, et al., 1990) especially for rainbow trout (Muhlfeld, 2002). In addition, pools are likely locations to observe the effects of excess fine sediment within a system (Kappesser, 2002; Cover, et al., 2008; Lisle, 1982). Grid toss counts of fine sediments will be performed in the tail of all scour pools (not formed by logs or some other debris completely damming the downstream end of the pool) within the sampling site. These pools must be at least 50% of the wetted channel width and have a maximum depth ≥ 1.5 times the pool-tail depth (Heitke, et al., 2010). If more than ten pools suitable for spawning are identified and time does not permit sampling every one, then the first 10 pools encountered within the site will be sampled. Three grid tosses will be performed in each of the pool tails (Heitke, et al., 2010); **Figure 4**). The intersections of the grid are approximately 6 mm and as a result, percent fines values for sediment <6 mm will be measured. The median size (D_{50}) of all particles observed under each grid toss will be recorded, to assure that the toss occurred on substrates that salmonids would in fact use for spawning (e.g., a grid toss on a locale that is almost all large cobble would not be used for spawning). Grid toss locations that are suitable or unsuitable for spawning can then be sorted during data analysis.



The figure is adapted from Heitke et al. (2010).
Figure 4. Locations within a pool tail to be sampled with the grid toss.

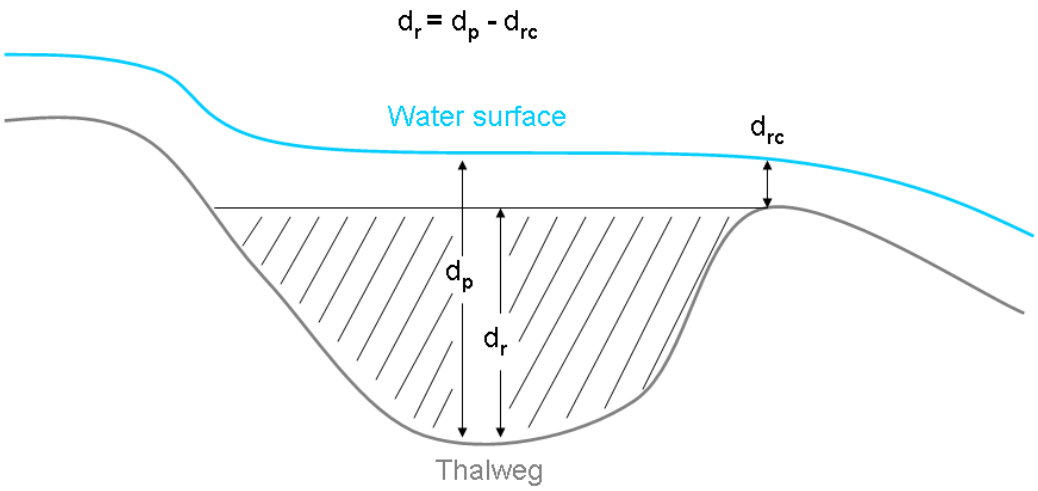
3.8 POOL FREQUENCY

Pool frequency is simply a count of the number of pools encountered within a sampling site. For a pool to be counted, it must occupy at least 50% of the wetted channel width and have a maximum depth ≥ 1.5 times the pool-tail depth (Heitke, et al., 2010). When conducting a pool count, it will be noted whether or not the pool is being influenced by woody debris (wood is acting as a dam or causing scour that forms a pool). Average pool spacing (and thus frequency) can be quite variable, from one channel width to nine or more, depending on the stream type, local setting, and amount of large woody debris present (Beschta and Platts, 1986; Bilby, 1984; Montgomery, et al., 1995; Keller and Melhorn, 1973). In addition, the narrower the stream, the more variable pool spacing becomes (Montgomery, et al., 1995). Despite the variability in this parameter and the need to carefully consider all possible factors that can affect it, Wood-Smith and Buffington (1996)(1996) were able to correctly classify disturbed and undisturbed watersheds with at least 90% accuracy when using this parameter and the ratio of mean residual pool depth to mean bankfull depth in discriminant function analysis. Because of the natural high variability of this parameter, it will be applied carefully in sediment impairment determination and will be tested to determine whether or not it may be better to use this parameter as a means for detecting change/stability of a stream through time.

3.9 RESIDUAL POOL DEPTH

Residual pool depth (RPD) has been linked to land management practices (Lisle and Hilton, 1992; Kershner, et al., 2004b); **Figure 5**). As a result, this metric will be collected within each sampling site. Pools in which RPD is measured must be formed by the scouring action of water (not formed by logs or some other debris completely damming the downstream end of the pool), be at least 50% of the wetted channel width and have a maximum depth ≥ 1.5 times the pool-tail depth (Heitke, et al., 2010). The benefit of using residual parameters over those measured based on wetted perimeter is that they are flow/stage independent (no discharge relationship needs to be determined), and give an indication of the minimum amount of available pool habitat (Lisle, 1987). To reduce error, the goal will be to collect

RPD from every pool within the site as Keim and Skaugset (2002) demonstrated that collecting residual pool volume data over a long sampling site may provide a better representation than looking at individual pools. If a stream site contains many pools (more than 20) and time does not permit sampling every one, then the first 20 pools encountered within the site will be sampled. This should effectively capture the variability within the site and reduce error (Lisle and Hilton, 1999; Hilton and Lisle, 1993). Instructions on how to collect residual pool depth can be found in **Appendix B**.



d_r = residual pool depth; d_p = total pool depth at the deepest point along the thalweg; d_{rc} = depth of the riffle crest at the thalweg.

Figure 5. Profile (adapted from Lisle 1987) of a pool and locations to measure when determining residual pool depth.

3.10 ROSGEN CHANNEL TYPE

At each site, measurements will be made to determine Rosgen channel type (A, B, C, etc.; (Rosgen, 1994; 1996); See **Figure 1** in (Rosgen, 1994) for a diagram of stream channel types). This method considers variables such as valley type, stream slope, sinuosity, width to depth ratio, and flood-prone area and will help ensure that similar streams are being compared. Because stream channels can transition from one type to another, the stage of channel evolution must be considered before stratifying streams based on Rosgen channel type. If a channel appears to be stable then stratifying may be appropriate. A channel transitioning from an E to a C for example, should not be stratified by this parameter. Reference data will be combined based on channel type when appropriate so that comparisons between reference and target sites are meaningful.

3.11 BIOLOGICAL DATA

Macroinvertebtrates and periphyton will be collected from each sampling site, (currently, DEQ does not sample fish as part of its assessment process) though biological samples do not need to be collected from the same location as the physical data to be used in analysis (see: *Data Collection Requirements*). These samples will be collected via DEQ protocol for the specific biological parameters that will be used in analysis of biological condition. All samples will be preserved and stored until after the physical habitat parameters have been analyzed. If it is determined that sediment levels are above natural based on the physical data (**Figure 6**), then the biological data may be examined as well.

4.0 CHARACTERIZATION OF EFFECTS

Although the physical parameters primarily address sediment impacts to fish, they are also applicable to diatoms and macroinvertebrates. As a result of this and DEQ actively developing biological indices for diatoms and macroinvertebrates, the biological indices used in forming impairment decisions will currently focus on these forms of biology. Macroinvertebrates will be collected using the Environmental Monitoring and Assessment Protocol's "reachwide" method (Montana Department of Environmental Quality, 2006a). Periphyton will be collected following the "Peri-1" method (Montana Department of Environmental Quality, 2005a). Currently, DEQ has Observed/Expected (O/E) metrics that will be used for sediment assessment (Feldman, 2006). These metrics are not diagnostic for sediment, but DEQ is in the process of developing and refining macroinvertebrate indices that will be sediment specific. Diatom indicators similar to those found in Bahls et al. (2008) that are diagnostic for sediment impairment at the Level III Ecoregion scale are now available for use.

Fish indices are not currently being developed by DEQ, but testing of those already developed for other States' aquatic systems (McCormick, et al., 2001; Hughes, et al., 2004; Hughes, et al., 1998; Mebane, et al., 2003) may prove useful in the decision making process. If DEQ does develop fish indicators and/or concludes already developed indices to be useful in the future, they could be easily added to the assessment process. Until DEQ has its own fish metrics, it is strongly recommended that data available on the Montana Fish Wildlife and Parks Montana Fisheries Information (MFISH) website (http://fwp.mt.gov/fishing/mFish/) be used in consultation with a trained fisheries biologist to determine if fish in the target waterbody are demonstrating impairment due to the sediment condition.

4.1 ANALYSIS

DEQ defines reference condition as the condition of a waterbody capable of supporting its present and future beneficial uses when all reasonable land, soil, and water conservation practices have been applied. For a waterbody to be reference, it does not need to be pristine. Instead, reference waterbodies are those that demonstrate few to no effects from anthropogenic sources and are supporting all applicable beneficial uses. Reference waterbodies are either Tier 1 (Natural Condition) or Tier 2 (Minimally Impacted Condition) as determined by criteria that have been considered with intensive, on site inspection and best professional judgment (Suplee, et al., 2005).

Data analysis will take place after one season of physical and biological data is collected. To compare sediment data collected from reference sites with that of impaired sites, a three step process will be used. First, the data will be grouped (by ecoregion, Strahler order, Rosgen channel type, etc., based on the judgement of the assessor) so that like streams and/or stream types are being compared. Second, specific non-parametric statistical tests will be used to determine whether target stream values are within those defined by the reference data (**Table 1**). These tests are appropriate because they have no distribution requirements and are suitable for situations that involve low sample numbers (Helsel and Hirsch, 1995). An alpha value of 0.25 will be used in statistical analysis of physical parameter data. This will help balance the likelihood of committing either a type I or type II error when comparing target stream data to reference data and is the same value used when assessing for nutrient impairment (Suplee and Sada de Suplee, 2011). When performing the analysis, data will be examined in the order defined by the following reference priority: 1) Internal and external (higher weight to internal reference data), 2) Internal, 3) External, and 4) Literature. Reference data used in the analysis will depend on what is currently available and/or what may be collected. Literature values should primarily be used to

support the results of reference data collected in the field. If the assessor does not deem literature values appropriate for a given waterbody, then this will be explained in the assessment.

The third step in data analysis involves examining biological data when 1-3 physical parameters are deemed to be outside of the reference condition. Biology for a discrete reach will be considered indicative of impairment when 25% or more metrics suggest biological limitation. For example, two macroinvertebrate samples and two periphyton samples have been collected from a mountain stream and the MMI scores are 64 and 40, O/E scores are 0.81 and 0.92, and the periphyton increaser indicates 25 – 30% and 55 – 60% likelihood of impairment. In this case, one of four metrics (periphyton increaser = 55 – 60%) suggest biological limitation as advised by the specific biological methods. Thus, biology is considered impaired and would be considered indicative of impairment for this reach. Best professional judgment may override this decision based on the data analysis.

Table 1. Metrics to be collected and the statistical methods used to test for physical differences between target streams and reference data and to determine harm to biology.
The preferred option is to compare target stream physical values to reference data sets.

Metric	Minimum n	Analysis
Percent Fines: < 2 mm < 5.7 mm Pool Tail Fines: < 6 mm	n = 1	<u>Using Reference Data Sets</u>: When < 4 samples are collected use the 1-Sample Wilcoxon Signed Rank Test: - The 'Variables' entered will be the values from the reference data. - The 'Test Median' will be the values determined from the 400 pebble count, total percent of all grid tosses, mean residual pool depth, or pool count from the target stream sample site (or average of all applicable sites). - α = 0.25 When ≥ 4 samples are collected use the Mann-Whitney U test - α = 0.25
Residual Pool Depth Pool Count	n = 3	<u>Using Literature Values or Targets</u>: Use the 1-Sample Wilcoxon Signed Rank Test: - The 'Variables' entered will be the values determined from the 400 pebble count, total percent of all grid tosses, mean residual pool depth, or pool count from each target stream site. - The 'Test Median' will be the literature or TMDL target value. - α = 0.25
Periphyton Increaser O/E	n = 2 (for each metric)	When ≥ 25% of all biological metrics suggest biological limitation, then biology is considered impaired.

If all physical parameters are within the acceptable range of reference, then biological measures do not need to be considered and the waterbody will be considered "not impaired" (**Figure 6**). If one to three of the parameters are not within the acceptable range of reference, then biology will be the determining factor as to whether or not the waterbody is considered "impaired." If the biology indicates non-impairment in this situation, a second season of sampling may take place, during which, the same parameters will be sampled again and/or the additional parameters found in **Appendix A** will be

considered. When four or more parameters are outside of the acceptable range of reference, the waterbody is considered "impaired".

When two years of data have been collected, all data will be combined for analysis unless there is reason to believe conditions have changed sufficiently since the first year of data collection to make this action inappropriate. If after two years of sampling the same outcome is reached, a decision shall be made based on the data collected and the best professional judgment of the assessor, a biologist (when possible), and DEQ management. This decision flow accepts that variability is inherent within streams and that cases may arise where components of the physical composition may seem degraded but without adverse impacts to the biology.

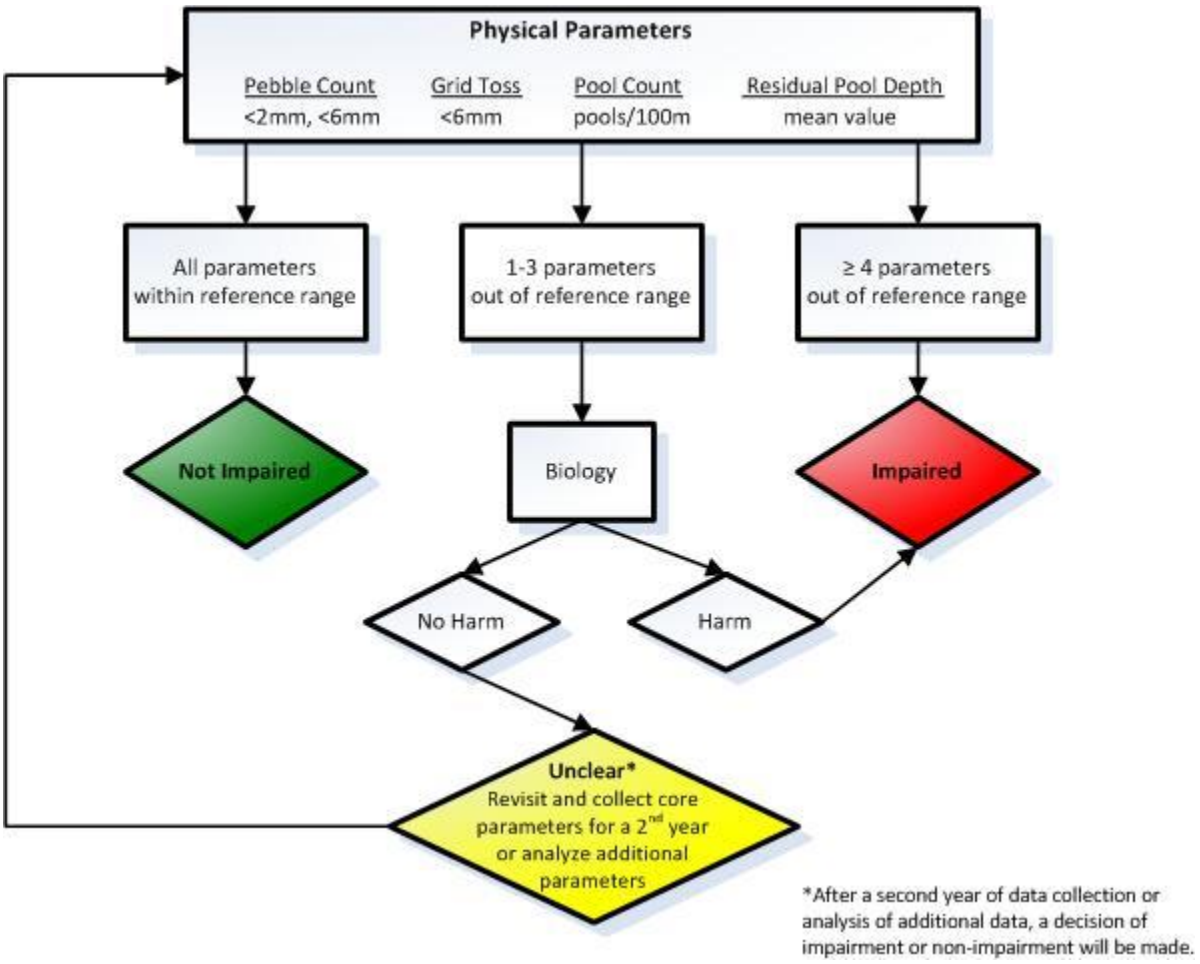


Figure 6. Decision flow chart for determining sediment impairment.

4.2 DATA FROM OTHER ENTITIES

DEQ realizes that other entities (federal and state agencies, contractors, landowners, etc.) may provide data that is relevant to the waterbody being assessed. This data will be considered in the formal assessment once it has been determined that it meets DEQ requirements for data quality. If data does not meet the requirements to be directly included in the DEQ collected dataset, it will be used to supplement the determination.

4.3 OVERWHELMING EVIDENCE

For evidence collected with this assessment method to be considered overwhelming (thus, leading to automatic placement on the 303(d) list), the following criteria must be met: 1) Known sources of sediment have been identified and documented and, 2) The target stream average value for a parameter is equal to or greater than the maximum value plus the median value for the same parameter from the applicable reference dataset. Only percent fine parameters (derived from pebble count and grid toss) will be used in overwhelming evidence-based decisions.

5.0 SUMMARY

Sediment is a leading cause of waterbody impairment in Montana. This pollutant can have a variety of adverse effects on many different aquatic organisms. Past listings for sediment were often based on best professional judgment with few standardized data quality objectives. The assessment method discussed in this paper is our attempt at developing a sediment impairment determination method that is both standardized and defendable. The parameters collected and the way in which they are measured are supported by the current peer-reviewed literature. The process we have developed to make an impairment decision helps account for natural variability and specifies when data is insufficient for a determination. The method described should lead to consistent and reproducible sediment impairment decisions.

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APPENDIX A. SECOND YEAR APPROACH

In cases where the decision flow chart indicates "at risk" after the first year of data collection, a second year of data collection must take place. The goal of collecting data during a second year is to capture temporal variability in the five core parameters and increase the rigor of the dataset. In addition, the second year of data collection provides an opportunity to use additional parameters that can help to answer specific questions. When planning the second year of data collection, a local biologist and/or hydrologist should be contacted (if feasible), to determine what additional parameters should be collected to appropriately address the issues in that particular waterbody. All data collected during the second year of sampling will be analyzed in the same manner as data collected during the first.

ADDITIONAL PARAMETERS

The following additional parameters are suggested to be collected when the core parameters discussed in the main portion of this document do not yield a straight forward determination with regards to sediment impairment. These parameters tend to require more time and resources to complete than performing those previously mentioned. As a result, they should be reserved for collection during the second season of sampling. If time and resources permit and/or a specific question needs to be answered, these additional parameters may be considered for integration into the initial assessment process. These parameters are to be used in addition to those previously discussed and should not be the sole determining factor in making a sediment impairment decision. To determine if these parameters are within the range of reference condition, the same approaches listed in **Table 1** of the main document shall be used.

RIFFLE STABILITY INDEX (RSI)

Riffle stability index (RSI) is an estimate of the mobile fraction of particles within a riffle. To calculate this index, the size distribution of particles collected from a riffle is compared to the mean size of dominant large particles collected from an adjacent depositional area (see Kappesser (2002) for the data collection methods). High RSI has been shown to correlate with reduced pool volume and be significantly different between reference and managed sites (Kappesser, 2002; Cross and Everest, 1995). In addition, Cross and Everest (1995) found bull trout (*Salvelinus confluentus*) redds nearly exclusively in reference streams with RSI less than 65. The relative ease of collection for this metric makes it a likely candidate for inclusion during the first season when core metrics are collected.

SUBSURFACE FINES

The subsurface substrate in gravel-bed rivers tends to be finer than that of the surface layer (Parker and Klingeman, 1982). Although the creation of redds by salmonids effectively reduces the amount of fines compared to non-redd substrate (McNeil and Ahnell, 1964; MacDonald, et al., 2010), over time, the interstices can refill with fine sediment (Zimmerman and Lapointe, 2005). Because salmonid embryo development takes place in subsurface substrate, evaluation of these particles may provide a better link to survival than surface fine measures. In much of the literature, the combined surface and subsurface composition of the substrate is considered (Fraley and Weaver, 1993; Tappel and Bjornn, 1983; Shepard, et al., 1984; Maret, et al., 1993; VanDusen, et al., 2005).

When sampling subsurface substrate, either McNeil cores (McNeil and Ahnell, 1964) or shovel samples may be collected (Grost, et al., 1991; Hames, et al., 1996; Young, et al., 1991). Young et al. (1991) determined that the McNeil core method most often yielded results that were similar to the true substrate composition though differences between the McNeil and shovel methods were few. Grost et al. (1991), was able to demonstrate that the two approaches yielded similar results in the field and suggested the use of a stilling well around the shovel to improve sampling accuracy. When a stilling well and shovel method was used by Hames et al. (1996), they found that this method compared relatively well to the McNeil method though they were unable to develop a conversion that would make the results of these two techniques comparable. Hames et al. (1996) made the recommendation that regardless of the method used, the same method should always be used so that data are comparable. For use by DEQ, it is recommended that the shovel technique with a stilling well be used to collect subsurface sediment samples. This method is less costly and requires the use of lighter equipment than the McNeil method (Grost, et al., 1991; Hames, et al., 1996). By using this method alone, DEQ will be using the method that is most efficient and appropriate for a variety of situations with minimal monetary investment for the collection of comparable and meaningful data. Shovel samples should be collected in suspected (pool-tails and the head of riffles (Reiser and Wesche, 1977)) or known spawning locations to provide data that are biologically relevant with regards to salmonid embryo development. If data from another method, such as McNeil coring has already been collected for the assessed waterbody, it is recommended that the same method be used to ensure data comparability.

INTRAGRAVEL DISSOLVED OXYGEN AND FLOW

Fine sediments less than 1 mm have been linked to reduced permeability in gravel (Kondolf, 2000). This reduction of permeability can reduce intragravel flow and thus, dissolved oxygen as well. Two distinct methods for sampling intragravel dissolved oxygen and flow are often used in the literature: 1) the standpipe (Coble, 1961; Barnard and McBain, 1994; Sowden and Power, 1985; Hansen, 1975; Terhune, 1958) and 2) the horizontal pipe (Maret, et al., 1993; Hoffman, 1986). The standpipe method has been used by DEQ (Suplee, 2008). The method used is dependent on the questions being asked. If a long term dataset (weeks, months, etc) with multiple or continuous measurements of dissolved oxygen at one location is desired, the horizontal pipe method is likely to be used. The standpipe method would be more appropriate when taking point measurements at multiple locations. Either of these approaches could be useful for developing a relationship between dissolved oxygen and some other variable such as percent fines or intragravel flow. The standpipe method is the method most likely to be used by DEQ, but the weight of materials required to perform it may limit its use as a supplemental indicator for sediment impairment. As a result, it is recommended that standpipes and methods to collect substrate dissolved oxygen in this way be modified (e.g., decreased pipe length and pipe pounder weight) to make its use less cumbersome for remote and difficult to access sites. As with subsurface sediment sampling, intragravel dissolved oxygen and flow should be sampled in known or suspected salmonid spawning locations.

RESIDUAL POOL VOLUME AND V*

Residual pool volume can be measured while collecting other residual pool parameters, but because it requires many more point measurements to calculate, it may be too time consuming for initial assessment purposes. V* or the fraction of pool volume filled with fine sediment as been shown to correlate with annual sediment yield and may be used to monitor the status of sediment supply in a system (Lisle and Hilton, 1999). This method can also help capture the effects of specific sediment inputs (Lisle and Hilton, 1992; Lisle and Hilton, 1991). V* is also linked to biological condition based on its

relationship to riffle-surface fine sediment (Cover, et al., 2008). This parameter uses the residual pool volume with the addition of measuring the volume of fine sediment deposits within a pool. Lisle and Hilton (1999; 1992; 1991) provide a synopsis of how residual pool volume and V* should be collected and how each can be used to monitor sediment loading in streams.

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APPENDIX B. FIELD METHODS

Order of Activities:

1. While moving upstream, measure the sediment site, and place flagging at the beginning and end of the sediment reach, and each riffle and pool within the reach.
2. While moving downstream, draw a map that indicates pool and riffle locations. Place flagging for the EMAP reach.
3. Collect macroinvertebrate and periphyton samples at each transect along the EMAP reach while moving upstream.
4. Return to the downstream end of the sediment reach. While moving upstream, measure residual pool depth, perform grid toss, and riffle pebble count.
5. Collect Rosgen Level II data.

1) Determine the downstream extent of the sampling site (this will be at the downstream extent of a riffle or pool) and use flagging to mark the location, record GPS coordinates, and photograph the area making sure to include landmarks (write this information as well as a brief description of the area on the photo form). The area upstream of this point will be the area you have pre-determined as being sampled. (Note if the location you have previously chosen for sampling does not meet the requirements necessary for the assessment (e.g. it is a transport reach, contains multiple stream types, etc.), or the location is inaccessible, the site can be moved to an appropriate location.)

2) Determine the site length.

I. Record five bankfull measurements: one at the downstream extent of the site, and then one at each of four more points working upstream from the initial measurement. Each measurement should be approximately two to three bankfull widths apart. Be careful to limit the amount of walking within the stream that takes place while making these measurements. Also be careful to limit substrate disturbance when walking in the stream.

II. Calculate the mean bankfull width for the five measurements. Multiply this value by 20. The result is the site length over which sampling will take place.

III. Use a measuring tape to follow one side of the stream along the bankfull width and measure the site length from the downstream extent. Upon reaching the upstream end of the bankfull channel, use flagging to mark the location, record GPS coordinates, and take a photograph of the area making sure to include landmarks (write this information as well as a brief description of the area on the photo form). If more than one channel exists, the one containing the higher discharge (ocular estimate) should be followed and measured. If the end of the sampling site does not coincide with the end of a habitat feature, extend the site upstream so that it ends at a habitat break that is the same as at the downstream end (e.g. pool tail to pool tail). Record the actual site length on the "Assessment Site Location, and Map" form. Leave the measuring tape along the bankfull width of the stream until you have finished sampling to facilitate naming and sampling features (you might need more than one measuring tape to delineate the site length depending on the length of the tape you are using and the site length).

IV. Return to the center of the sediment reach and record five wetted widths using the measuring tape. Measure the first one at the center of the reach, two upstream of the center, and two downstream of the center. Take the measurements from places considered to be the *typical wetted width* of the stream. Average the measurements and multiply by 40. If the final value is less than 150 m, use 150 m as the minimum reach length. Divide the total reach length by 10 to determine the distance between each transect. Place flagging at the center transect. Label the

flagging at this transect "F." Proceed upstream along the shore of the stream and flag each transect at intervals 1/10 of the reach length (labeled "G" through "K"; **Figure 3**). Then, proceed downstream, and repeat the process for the downstream portion of the EMAP reach (labeled "E" through "A"). Note: When the EMAP reach extends beyond the sediment reach, you will take photos of both ends of the EMAP reach facing inwards (i.e. upstream at Transect A, and downstream at Transect K) to show that the EMAP reach is still representative of the sediment reach. If the ends of the EMAP reach do not represent the setting of the sediment reach you will shift the EMAP reach either up or downstream until they are relatively the same.

3) Collect Biological Samples.

I. Macroinvertebrate samples will be collected using a 500 µg mesh D-shaped net (MDEQ 2006; MDEQ 2005b). To collect the sample, place the net at the established locale along each transect (right, left, or center) with the flat portion of the net frame firmly against the substrate. Manually pick up and clean all large particles (greater than golf ball size) at least halfway within a visually estimated 1ft² area directly upstream of the net mouth so that everything cleaned off of the particles flows into the net. After the particles are cleaned, discard them downstream of the net. All large particles that are not at least halfway within the 1ft² area will be moved to the side. After all of the large particles are cleaned, use your feet to stir up the stream bottom within the same 1ft² area for 30 seconds (use a stopwatch). Once the kick is finished, remove the net from the water. Next, dip the net into the water several times so that fine sediments, detritus, and organisms concentrate at the end of the net. Be sure to avoid allowing any water or material to enter the mouth of the net during this process. Invert the net into a 500 µg sieve and pick any organisms off of the net using forceps and place into the sieve. Place all material from the sieve (clean substrate particles, bark, and leaves can be removed from the sample) into a labeled 1 L bottle and fill with 95% ethanol. Once a bottle is 50% filled with material, the remaining sample will be placed into (an) additional bottle(s) and topped off with ethanol. Optional: You can elutriate the sample in a 5 gallon bucket to reduce the amount of sediment in the final sample. You do this by emptying the contents of the D-frame net into the bucket and adding enough water to the bucket to float organic material away from the inorganic material. Vigorously stir the contents and then pour the liquid into a sieve. You can then transfer the sieve contents to the sample jar. After you are certain that you have removed 90 – 95% of the organic portion from the sample, you may discard the remaining substrate to the stream and preserve the sample in ETOH.

You will collect macroinvertebrates in the EMAP reach following the "right," "left," "center" pattern. So, at Transect A, you will collect the periphyton from the right locale of the channel. Afterward, you will collect the next portion of the sample from the left locale at Transect B. You will then collect the next sample portion from the center locale at Transect C. The blue circles on **Figure 3** demonstrate where the macroinvertebrate samples should be collected throughout the EMAP reach.

II. The PERI-1mod method (i.e., *modified* PERI-1) is used with the EMAP reachwide approach (MDEQ 2006; MDEQ 2005b). It is a single composite sample that is a miniature replica of the stand of algae which are present at the study site. You will collect both micro- and macroalgae using this protocol.

Starting from the most downstream transect, at each of the 11 transect sampling locales algal material should be collected from substrate representative of the right, left, or center locale. Collection tools should include a toothbrush or test-tube brush, a small pocket knife, a turkey baster (used to suck up fine sediments), a small stainless steel spoon, and a plastic tray to place the material in prior to transfer to the storage container. The standard storage container, a 50

cm3 centrifuge tube, is fairly small and will fill quickly; do not over-add any particular batch of sampled material. To aide in this, larger volumes of material collected in the plastic tray can be sub-sampled and the subsample transferred to the centrifuge tube. Be sure to thoroughly mix the material prior to sub-sampling.

As the collector works his/her way upstream, it should be noted whether or not any substrate type that is common along the site has been precluded from sampling due to the manner in which the 11 transects happen to have fallen along the longitudinal length. If an important substrate type has been precluded the sampler should, after completing the uppermost transect, return to the substrate in question and collect algae in an amount approximately proportional to the substrate's presence in the reach.

You will collect periphyton in the EMAP reach following the "center," "right," "left" pattern. So, at Transect A, you will collect the periphyton from the center of the channel. Afterward, you will collect the next portion of the sample from the right locale at Transect B. You will then collect the next sample portion from the left locale at Transect C. The red circles on **Figure 3** demonstrate where the periphyton samples should be collected throughout the EMAP reach.

4) Identify pools and riffles for sampling, and map the site.

I. Working in a downstream direction (from the top of the site), identify pools that, visually approximated, occupy at least 50% of the wetted channel width at one location in the main channel and have a maximum depth ≥ 1.5 times the pool-tail depth along the pool's thalweg. Also identify riffles. **Figure 1**, shows a longitudinal profile of a pool and a riffle and the different portions of each. Pools will be identified following the thalweg. Look upstream at the water surface for slope breaks to help identify features (the water surface will look sloped in riffles, but flat in pools).

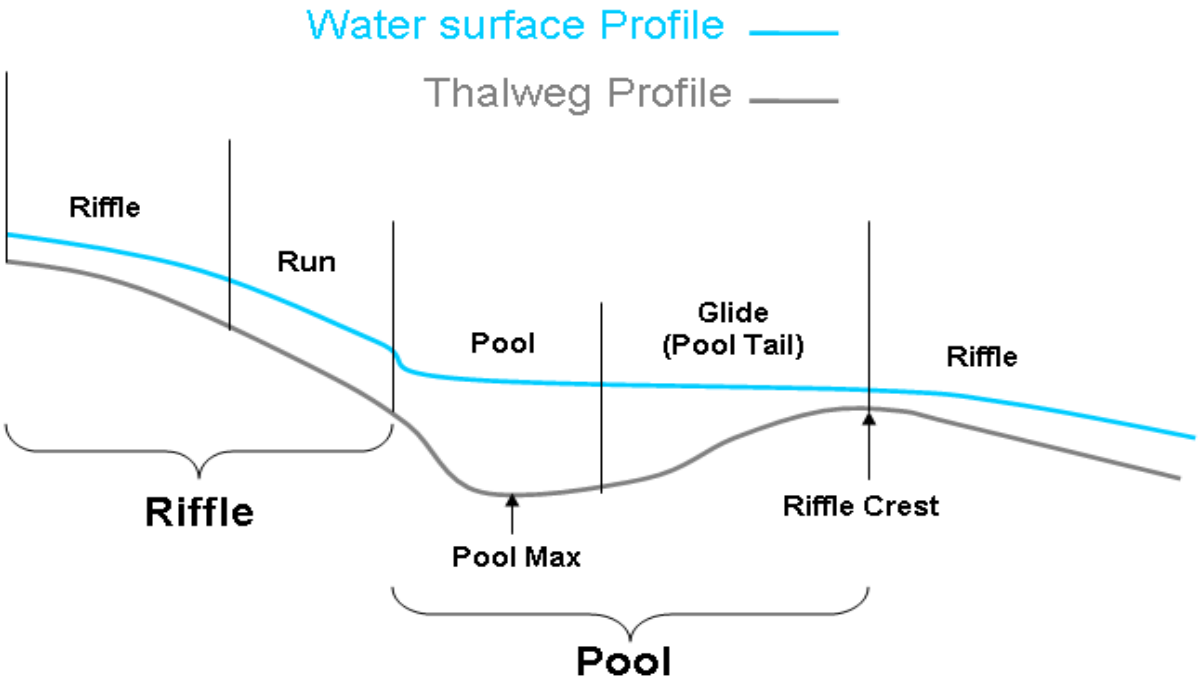


Figure 1. Longitudinal profile of a stream bottom along the thalweg and the water surface.
For this assessment, run habitat will be considered riffle, and glide habitat will be considered pool.

II. Draw a map on the field form as you work in the downstream direction, referencing the most downstream location of pools, riffles, and pool-forming woody debris (with reference to the distance from the downstream extent of the site; **Figure 2**).

III. After mapping the site, label each pool and riffle with a number and a distance from the downstream extent of the site, starting at the bottom of the site (e.g., R1-0 and P1-40), increasing the number in the upstream direction (**Figure 2**). Put the corresponding information in the "Riffle and Pool Count Form." For each pool counted, mark (Yes/No) if the pool is formed, in any way, by woody debris and/or boulders. Also mark which features will be sampled with a pebble count, grid toss, and/or for residual pool depth (this can be done as you move back upstream and individually assess the suitability of each feature for a given measurement).

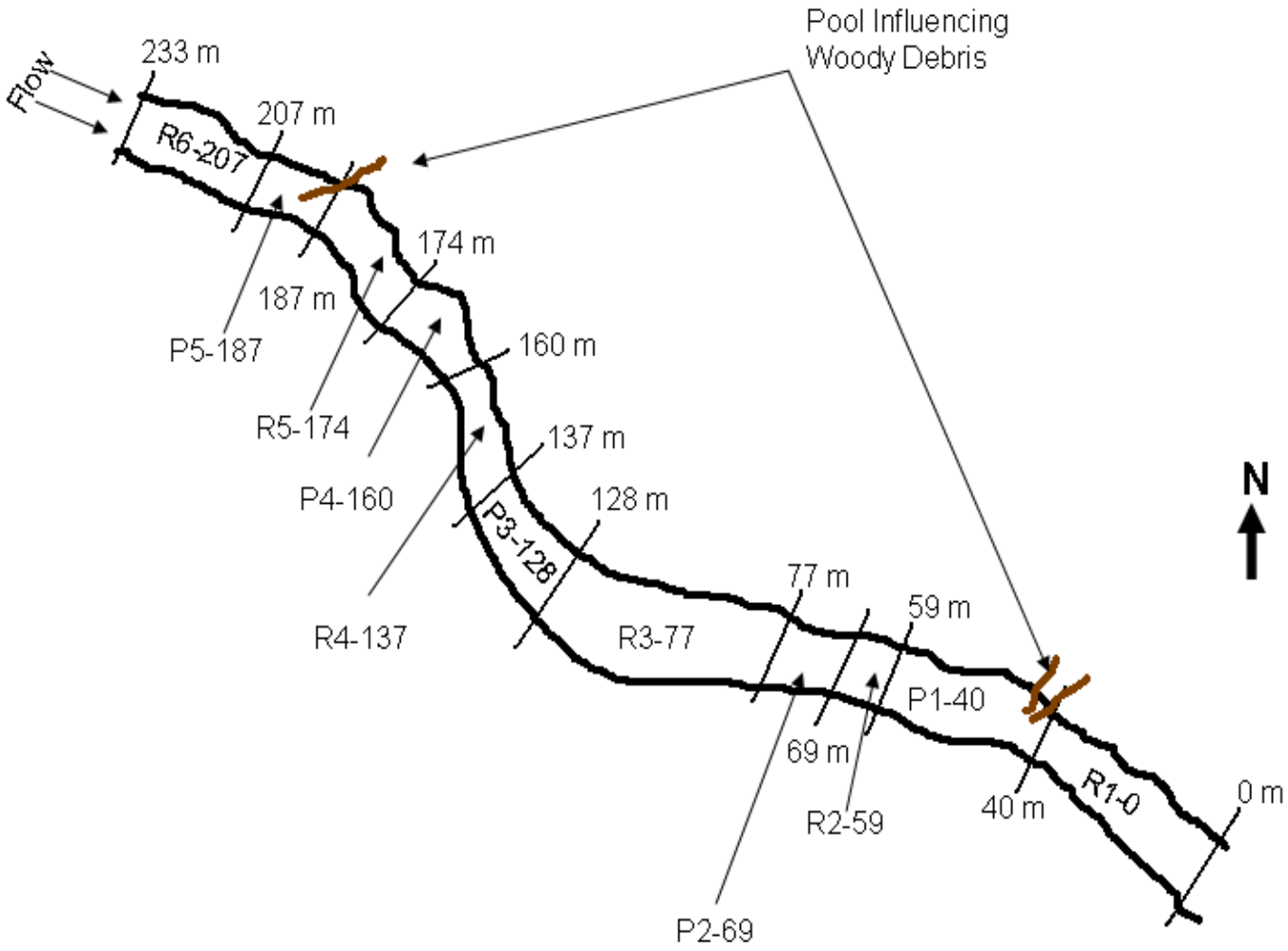


Figure 2. Example of a sediment reach map drawn at the sampling site.

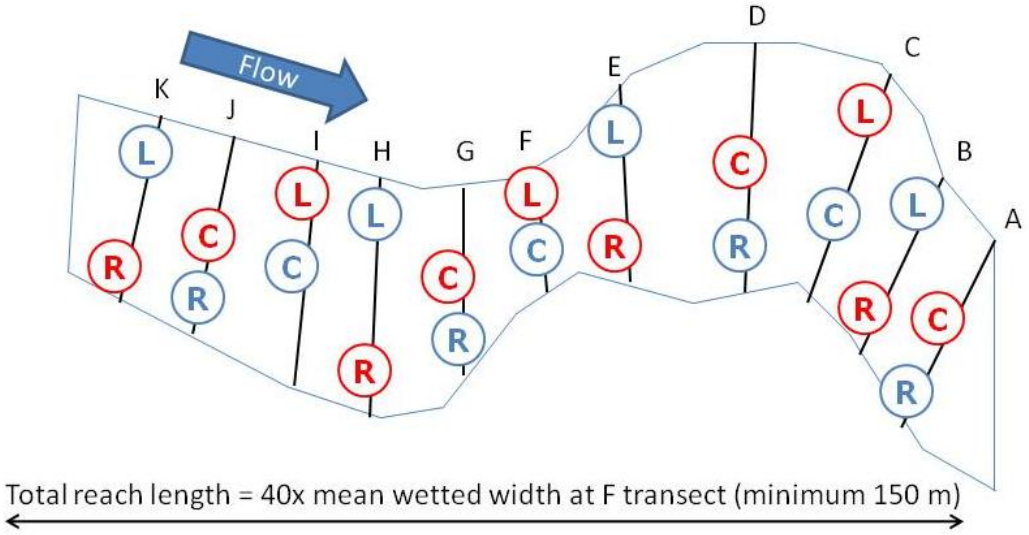


Figure 3. An example of the EMAP sampling reach for biological samples. The blue and red circles indicate the respective macroinvertebrate and periphyton sampling locations at each transect.

5) Collect pool-tail grid toss, and riffle pebble count. Working in the upstream direction, perform the appropriate sampling depending on the feature encountered.

If a pool is encountered, perform a grid toss and measure residual pool depth:

I. For a grid toss to take place in a pool, the pool must: 1) be formed by the scouring action of water (not formed by logs or some other debris damming the downstream end of the pool; partial damming of the pool is acceptable as long as a scour-formed pool tail is present), 2) visually approximated, occupy at least 50% of the wetted channel width at one location in the main channel and have a maximum depth ≥ 1.5 times the pool-tail depth along the pool's thalweg.

II. Every pool suitable for measuring pool-tail fines within a site should be measured. If more than ten suitable pools are present and time does not allow, the first ten encountered within the site will be sampled with the grid toss.

III. Sample the pool tail by working from river right to river left by tossing the grid at points 25%, 50%, and 75% across the pool's wetted width at a distance that is 10% of the pool's length or 1 m from the pool tail crest, whichever is less (**Figure 4**). Be sure to follow the contour of the pool tail when making the tosses. For each of the 49 internal intersections on the grid, count how many completely cover particles (each intersection is approximately 6 mm). Mark this number on the "Residual Pool Depth and Pool Tail Fines" field form. For each toss, estimate the median (i.e., D_{50}) substrate size class of the substrate under the grid. Mark this estimate in the appropriate box as: s = sand (< 2 mm), g = gravel (2 mm - 64 mm), c = cobble (64 mm – 256 mm), b = boulder (256 mm - 2048 mm), and bd = bedrock (> 2048 mm). If a portion of the grid lands on a particle that is a small boulder or larger (> 512 mm b-axis), do not assess the intersections that fall on such substrate. On the field form, record the number of particles < 6 mm out of the number assessed (e.g., 8/40). If, in small streams, the grid tosses overlap, note in the

"Comments" section of the field form to indicate that overlap occurred. If algae or organic debris on the streambed blocks visual identification of the particles underneath, do not move the obstruction. Record the number of intersections covering particles < 6 mm out of those that are not obstructed and can be assessed on the field form.

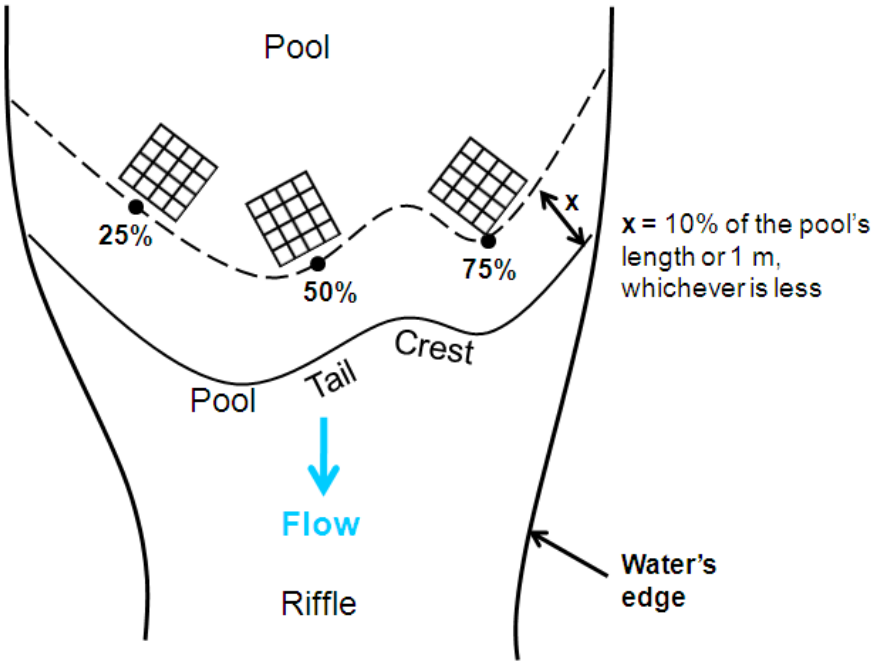
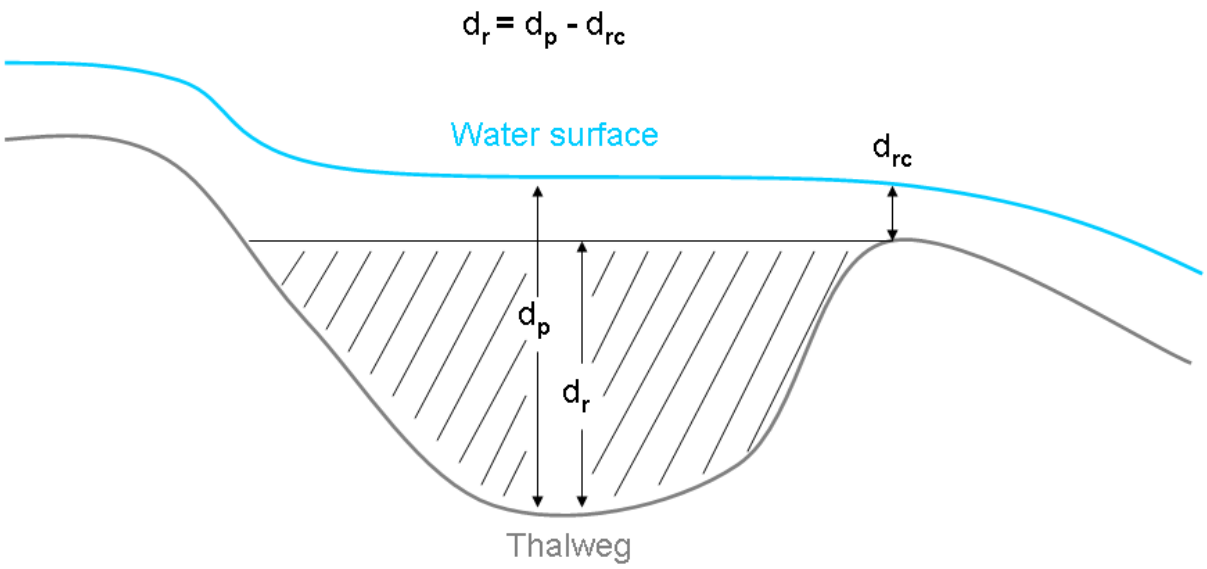


Figure 4. Locations within a pool tail to be sampled with the grid toss (figure is adapted from Heitke et al. 2010).

IV. For RPD to be measured, the pool must: 1) be formed by the scouring action of water (not formed by logs or some other debris damming the downstream end of the pool; partial damming of the pool is acceptable as long as a scour-formed pool tail is present) and 2) visually approximated, occupy at least 50% of the wetted channel width at one location in the main channel and have a maximum depth ≥ 1.5 times the pool-tail depth along the pool's thalweg.

V. Every pool suitable for measuring RPD within a site should be measured. If more than 20 pools are present and time does not allow sampling all of the pools, sample the first 20 that are encountered within the site.

VI. To measure RPD, use a stadia rod to measure from the substrate surface to the water surface at two locations: 1) the deepest point in the pool along the thalweg (d_p) and 2) the depth of the riffle crest at the thalweg (d_{rc}) (**Figure 5**). The RPD (d_r) = d_p - d_{rc}. Record both measurements and the calculated RPD on the "Residual Pool Depth and Pool Tail Fines" field form.



d_r = residual pool depth; d_p = total pool depth at the deepest point along the thalweg; d_{rc} = depth of the riffle crest at the thalweg.

Figure 5. Profile of a pool and locations to measure when determining residual pool depth (adapted from Lisle 1987).

If the pool is too deep to wade, measure the depth of the pool from the side, where it is wadeable and calculate the depth using **Figure 6** and the following equations.

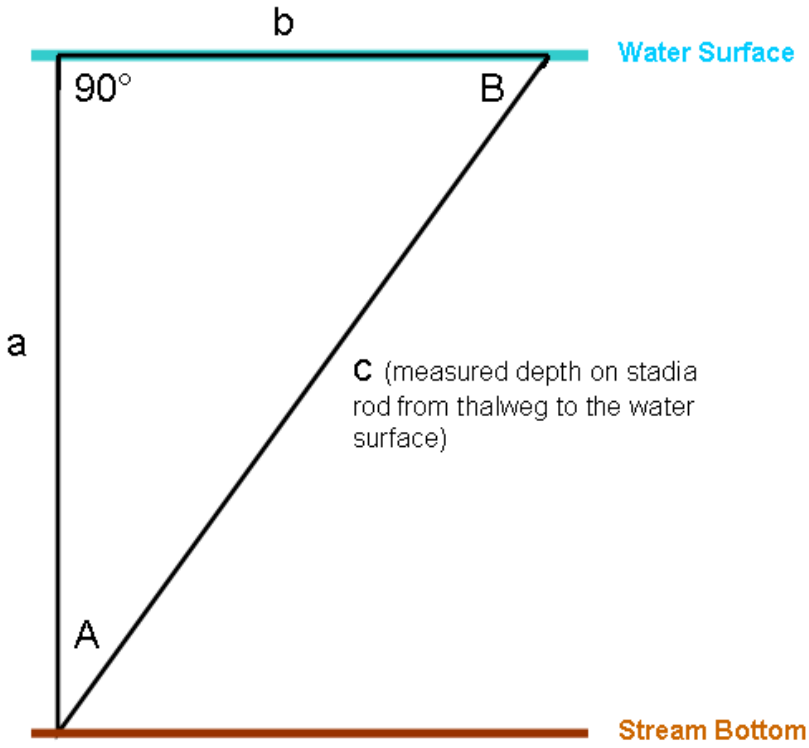


Figure 6. Trigonometric values used to determine depth of a pool if the pool is too deep to wade.

Step 1: Estimate angle **B** using a large compass or clinometer (water surface relative to stadia rod measurement)
Step 2: Determine angle **A** as: **A** = 180 – [90 + **B**]
Step 3: **b** (actual depth of pool) = **c** cos **A**

Note that the actual depth was calculated in the "Comments" section of the "Residual Pool Depth and Pool Tail Fines" field form.

If a riffle is encountered, perform the riffle pebble count:

I. Four riffles will be sampled, each with a 100 pebble count. If more than four riffles are present, sample those that have been chosen by a random number generator in **Table 1**. If fewer than four riffles are present, a total of 400 particles will still be counted. The count will be spread out evenly among the riffles that are present using the same four-transect setup (e.g., if two riffles are present, each will have a 200 particle count with each sampling location being a maximum of 1/50 of the bankfull width apart). If no riffles are present within the reach, a riffle pebble count will not be performed.

Number of Riffles	Riffles to sample	Number of Riffles	Riffles to sample
5	1,2,4,5	26	2,5,11,25
6	1,4,5,6	27	6,10,11,18
7	2,4,5,7	28	11,17,19,28
8	1,4,6,7	29	5,13,16,18
9	1,5,6,7	30	7,12,29,30
10	2,4,6,8	31	3,15,20,28
11	1,2,3,5	32	11,20,21,24
12	2,4,6,7	33	10,12,19,23
13	3,7,9,13	34	1,15,24,28
14	7,9,11,13	35	2,9,23,32
15	2,4,6,7	36	3,9,31,32
16	1,4,7,10	37	8,22,25,33
17	2,4,14,16	38	1,13,20,26
18	3,6,10,16	39	12,20,22,24
19	1,2,6,10	40	17,21,24,31
20	1,7,10,14	41	16,26,27,28
21	2,5,14,16	42	14,30,35,40
22	4,8,14,22	43	12,6,33,34
23	11,12,15,19	44	5,10,16,22
24	2,6,11,23	45	3,26,31,45
25	5,15,20,23	46	12,16,26,27

Table 1. Riffles to be sampled when more than four are present within a site.

II. Measure the length of the riffle. Within each riffle, four (measuring tape) transects will be evenly distributed (from downstream to upstream) at 20, 40, 60, and 80% of the riffle length.

Along each transect, 25 sampling locations (assuming a 100 pebble count; it would be at 38 locations for a 152 pebble count) will be evenly spaced within the bankfull width so that the maximum distance between each is 1/25 of the bankfull width (use a calculator to determine the distance at which each particle should be selected and round the value down to ensure that at least 25 particles are sampled; (**Figure 7**)). Bankfull width will be recorded for each pebble count transect.

III. To sample the riffle, start at the downstream transect and sample from river right to river left, then proceed to the next upstream transect and sample from river left to river right, and repeat this pattern as moving upstream to the final two transects (**Figure 7**). Begin sampling at 0 on the measuring tape every other transect. Standing downstream of the transect tape, select each particle by placing the sampling frame rod at the location on the measuring tape (e.g., the 1/25 distance) with the sampling frame on the downstream side of the rod (between you and the rod) and lowering the sampling frame to the substrate. If you can see the sampling frame intersection, select the particle that is directly below. If not, reach down and feel the intersection of the rubber bands on the sampling frame and then select the particle that you can feel directly below. Placing a binder clip on the measuring tape at the sampling location helps to track each location as it is sampled. If you cannot place the sampling frame on the downstream side of the tape due to woody debris, place the frame on the upstream side of the tape as close to the appropriate measurement distance as possible. Return to placing the sampling frame on the downstream side of the tape as soon as the obstruction is no longer present. Attempt to carefully move algae/vegetative mats covering the substrate so that the sampling frame can be put into place. If algae/vegetation cannot be moved, place the sampling frame on the upstream side of the tape as would be done in the case of woody debris.

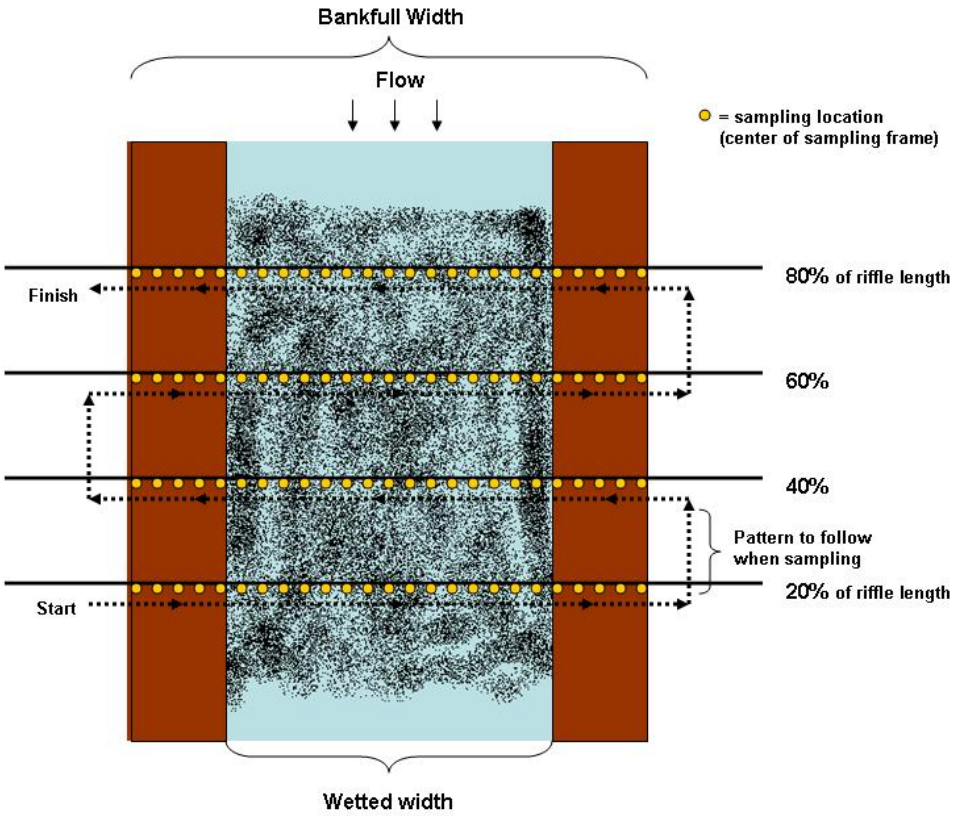


Figure 7. Setup for performing a riffle pebble count.

V. Measure each particle by finding the smallest hole in the gravelometer that the particle will fit through (if the particle fits through the 22.6 mm opening but not the 16 mm opening, the particle will be recorded within the "16.1-22.6 mm" size box). For particles less than 4 mm, use the edge (width) of the gravelometer to measure the particle's intermediate axis to determine if the particle is within the 2.1 – 4 mm or < 2 mm size category. Particles greater than 128.1 mm will be measured along the edge of the gravelometer. Particles greater than 2056 mm are considered bedrock and will be visually estimated. The 6.35 hole **will not** be used to measure particles. After measuring a particle, place it downstream of the transect so that it is not measured again. If the particle cannot be moved from the stream bottom, estimate its size. If the particle cannot be moved from the stream bottom and the sampling frame falls on it multiple times, record each time as an individual count. Particle size data will be recorded on the "DEQ Sediment Assessment Pebble Count" field form using the "dot/slash" system where 10 particles =  . The four dots should be filled in first, followed by the outside lines of the box, and, finally, the diagonal lines.

VI. Mark each particle on the form in the appropriate location: under "Wet" if collected within the wetted channel, and under "Dry" if collected between the water's edge and bankfull. For Dry samples collected between the water's edge and bankfull, note if the particle appears to have been deposited by the relatively recent action of flowing water (fluvial) or if it is older, established bank soil or substrate (non-fluvial). Record the particle size in the categories provided, as appropriate.

6) Perform Rosgen Stream Classification measurements.

A channel cross section will be measured using a laser level at the crest of one of the pebble count sampled riffles. Note on the field form which of the riffles was measured. To measure the cross section, follow the instructions in **Figures 9** and **10** (MDEQ 2005b). This data will be entered on the "Laser Level Channel Cross-Section" and "Stream Classification" forms.

B. **Channel Cross Sections (Laser level and Non-laser level)**
The cross section method contains elements of a Rosgen Level II measurements but should not be confused with the complete Rosgen Stream Classification, which is an *optional* physical measurement.

Laser Level Cross-Section Method /

- Setup the surveying instrument in a location where the entire cross section can be viewed. The instrument should be placed at an elevation higher than the highest feature required for the survey. Ideally, only one instrument setup will be required to survey the entire cross section; however, determining the width of the flood prone area may require multiple instruments setups due to dense foliage.
- Stretch the tape across the channel (zero on left bank) making sure the tape is perpendicular to the direction of the flow.
- Hammer Survey Stakes on each side past bankfull elevation. Attach the tape and adjust the tension until the tape is tight.
- Begin the cross section survey: Place the surveying rod at major breaks in bed elevation and key features such as left bankfull (LBF), left edge water (LEW), Thalweg (THL), right edge water (REW), right bankfull (RBF). See attached example.
- Record the distance point or station (ft), the corresponding Fore-Sight (ft), and the Height Depth or Elevation (ft). **See Attachment B**
- Measure the flood-prone area width (Width of the channel at an elevation that is 2 times the maximum bankfull depth).
- Calculate the bankfull cross sectional area and plot your cross section.
- Calculate mean depth, width/depth ratio and entrenchment ratio.
- Using the appropriate regional curves, check to make sure your cross sectional area, bankfull width and depth are reasonable. Make sure your bankfull velocity is reasonable (Velocity = Bankfull Discharge/Bankfull Area).

Figure 9. Procedure to measure cross sections for Rosgen channel type classification (figure from MDEQ 2005b).

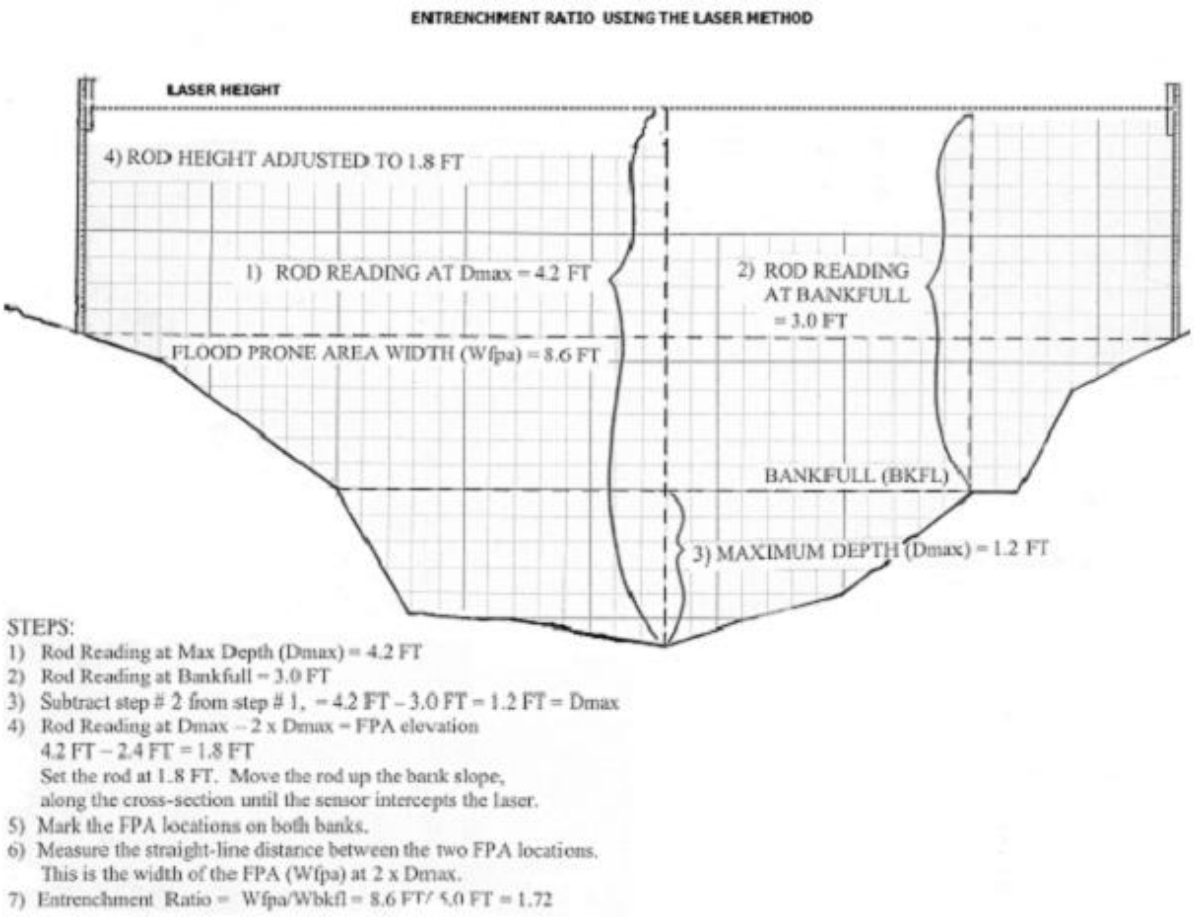


Figure 10. Diagram of a stream cross section, description of measurements, and order in which measurements should be made (figure from MDEQ 2005b).

APPENDIX C. FIELD FORMS

The following pages are the field forms to be used when collecting the primary metrics of the sediment assessment protocol. Field forms for secondary metrics have not been developed at this time.

Sediment Assessment Site Location and Map Form Reviewed by _____

SITE NAME:_____	**DATE:**_____	**SITE VISIT CODE:**_____
SITE ID: _____	**PERSONNEL:** _____	

STREAM/RIVER SITE DETERMINATION					
Latitude (NAD 83)	Longitude (NAD 83)	Bkf Measures (m)	Mean Bkf Width (m)	Calculated Site Length (m)	Actual Site Length (m)
At Downstream End of Site					
At Upstream End of Site					

SKETCH MAP – Arrow Indicates North

Comments:

Riffle and Pool Count Form

Date: ____________________ **Site Visit Code:** ____________________

Waterbody: ____________________

Personnel: ____________________

Record each structure starting at the downstream extent of the site and moving upstream, circling the appropriate option under each heading. Label structures as in "Name" as "R1-2.7" for the first riffle located 2.7m from the bottom extent of the site, "P1-10.2" for the first pool located 10.2 m from the bottom extent of the site, "R2-15.6" for the second riffle, etc. "Wood influenced" and "Boulder Influenced" pertains to pools only and could be damming the stream to form the pool or simply causing scour. The "Pebble Ct" will only take place in riffles and the "Grid Toss" and "Residual Pool Depth" only in scour pools.

Structure	Name	Wood Influenced	Boulder Influenced	Pebble Ct	Grid Toss	Residual Pool Depth
Pool Riffle		Yes No	Yes No	Yes No	Yes No	Yes No
Pool Riffle		Yes No	Yes No	Yes No	Yes No	Yes No
Pool Riffle		Yes No	Yes No	Yes No	Yes No	Yes No
Pool Riffle		Yes No	Yes No	Yes No	Yes No	Yes No
Pool Riffle		Yes No	Yes No	Yes No	Yes No	Yes No
Pool Riffle		Yes No	Yes No	Yes No	Yes No	Yes No
Pool Riffle		Yes No	Yes No	Yes No	Yes No	Yes No
Pool Riffle		Yes No	Yes No	Yes No	Yes No	Yes No
Pool Riffle		Yes No	Yes No	Yes No	Yes No	Yes No
Pool Riffle		Yes No	Yes No	Yes No	Yes No	Yes No
Pool Riffle		Yes No	Yes No	Yes No	Yes No	Yes No
Pool Riffle		Yes No	Yes No	Yes No	Yes No	Yes No
Pool Riffle		Yes No	Yes No	Yes No	Yes No	Yes No
Pool Riffle		Yes No	Yes No	Yes No	Yes No	Yes No
Pool Riffle		Yes No	Yes No	Yes No	Yes No	Yes No
Pool Riffle		Yes No	Yes No	Yes No	Yes No	Yes No
Pool Riffle		Yes No	Yes No	Yes No	Yes No	Yes No
Pool Riffle		Yes No	Yes No	Yes No	Yes No	Yes No
Pool Riffle		Yes No	Yes No	Yes No	Yes No	Yes No
Pool Riffle		Yes No	Yes No	Yes No	Yes No	Yes No
Pool Riffle		Yes No	Yes No	Yes No	Yes No	Yes No
Pool Riffle		Yes No	Yes No	Yes No	Yes No	Yes No
Pool Riffle		Yes No	Yes No	Yes No	Yes No	Yes No
Pool Riffle		Yes No	Yes No	Yes No	Yes No	Yes No
Pool Riffle		Yes No	Yes No	Yes No	Yes No	Yes No
Pool Riffle		Yes No	Yes No	Yes No	Yes No	Yes No
Pool Riffle		Yes No	Yes No	Yes No	Yes No	Yes No
Pool Riffle		Yes No	Yes No	Yes No	Yes No	Yes No
Pool Riffle		Yes No	Yes No	Yes No	Yes No	Yes No
Pool Riffle		Yes No	Yes No	Yes No	Yes No	Yes No
Pool Riffle		Yes No	Yes No	Yes No	Yes No	Yes No

Comments:

DEQ Sediment Assessment Pebble Count - for ONE Riffle

Date: **Site Visit Code:**

Waterbody:

Personnel:

This form only pertains to riffles. Each transect will have a minimum "**Total #**" of 25 particles counted per transect. Write the transect width next to each transect heading ("**Transect 1 w: 2.5 m**" for example). **Transect 1** = location at 20% of riffle length from the bottom of the riffle extent, **Transect 2** = location at 40% of riffle length from the bottom of the riffle extent, **Transect 3** = location at 60% of riffle length from the bottom of the riffle extent, and **Transect 4** = location at 80% of riffle length from the bottom of the riffle extent. "Sample Spacing" is the distance between each particle measured and is calculated as: Transect width/# of particles to be sampled per transect (e.g. 10.5/25 = 0.4, when the quotient is rounded down from 0.42). **"Wet"** particles are collected from the wetted channel, **"Dry"** are collected between bankfull and the wetted channel.

RIFFLE #: R

Size (mm)	Transect 1 w:			Transect 2 w:			Transect 3 w:			Transect 4 w:		
	Sample Spacing:			Sample Spacing:			Sample Spacing:			Sample Spacing:		
	Wet	Dry		Wet	Dry		Wet	Dry		Wet	Dry	
		Fluvial	Non-Fluvial		Fluvial	Non-Fluvial		Fluvial	Non-Fluvial		Fluvial	Non-Fluvial
< 2[1]												
2.1 - 4												
4.1 - 5.7												
5.7 - 8												
8.1 - 11.3												
11.4 - 16												
16.1 - 22.6												
22.7 - 32												
32.1 - 45												
45.1 - 64												
64.1 - 90												
90.1 - 128												
> 128												
Total #												

[1] **As measured across the b-axis against the width of the edge of the gravelometer**

Comments:

Residual Pool Depth and Pool Tail Fines

Date:

Waterbody: **Site Visit Code:**

Personnel:

This form pertains only to pools. Write in the appropriate number for each pool name. For **"Residual Pool Depth"**: dr = residual pool depth; dp = total pool depth at the deepest point along the thalweg; drc = depth of the riffle crest at the thalweg. For **"Grid Results"**: Starting on river right, T1 = 25% of the wetted width, T2 = 50% of the wetted width, T3 = 75% of the wetted width, and Total = the combined values from all three counts. Values should be entered as: (# of fines < 6 mm) / (# of intersections assessed). The dominant substrate lying under each toss should be marked in "D50:" as: s = sand (<2 mm), g = gravel (2 mm - 64 mm), c = cobble (64 mm - 256), b = boulder (256 mm - 2048 mm), and bd = bedrock (>2048 mm). Note in the **"Comments"** section if any tosses overlapped by providing the name of the pool and the numbers for the tosses that overlapped.

Name	Residual Pool Depth			Grid Results						
P	d_p =	d_{rc} =	d_r =	T1: /	D50:	T2: /	D50:	T3: /	D50:	Total: /
P	d_p =	d_{rc} =	d_r =	T1: /	D50:	T2: /	D50:	T3: /	D50:	Total: /
P	d_p =	d_{rc} =	d_r =	T1: /	D50:	T2: /	D50:	T3: /	D50:	Total: /
P	d_p =	d_{rc} =	d_r =	T1: /	D50:	T2: /	D50:	T3: /	D50:	Total: /
P	d_p =	d_{rc} =	d_r =	T1: /	D50:	T2: /	D50:	T3: /	D50:	Total: /
P	d_p =	d_{rc} =	d_r =	T1: /	D50:	T2: /	D50:	T3: /	D50:	Total: /
P	d_p =	d_{rc} =	d_r =	T1: /	D50:	T2: /	D50:	T3: /	D50:	Total: /
P	d_p =	d_{rc} =	d_r =	T1: /	D50:	T2: /	D50:	T3: /	D50:	Total: /
P	d_p =	d_{rc} =	d_r =	T1: /	D50:	T2: /	D50:	T3: /	D50:	Total: /
P	d_p =	d_{rc} =	d_r =	T1: /	D50:	T2: /	D50:	T3: /	D50:	Total: /
P	d_p =	d_{rc} =	d_r =	T1: /	D50:	T2: /	D50:	T3: /	D50:	Total: /
P	d_p =	d_{rc} =	d_r =	T1: /	D50:	T2: /	D50:	T3: /	D50:	Total: /
P	d_p =	d_{rc} =	d_r =	T1: /	D50:	T2: /	D50:	T3: /	D50:	Total: /
P	d_p =	d_{rc} =	d_r =	T1: /	D50:	T2: /	D50:	T3: /	D50:	Total: /
P	d_p =	d_{rc} =	d_r =	T1: /	D50:	T2: /	D50:	T3: /	D50:	Total: /
P	d_p =	d_{rc} =	d_r =	T1: /	D50:	T2: /	D50:	T3: /	D50:	Total: /
P	d_p =	d_{rc} =	d_r =	T1: /	D50:	T2: /	D50:	T3: /	D50:	Total: /
P	d_p =	d_{rc} =	d_r =	T1: /	D50:	T2: /	D50:	T3: /	D50:	Total: /
P	d_p =	d_{rc} =	d_r =	T1: /	D50:	T2: /	D50:	T3: /	D50:	Total: /
P	d_p =	d_{rc} =	d_r =	T1: /	D50:	T2: /	D50:	T3: /	D50:	Total: /
P	d_p =	d_{rc} =	d_r =	T1: /	D50:	T2: /	D50:	T3: /	D50:	Total: /
P	d_p =	d_{rc} =	d_r =	T1: /	D50:	T2: /	D50:	T3: /	D50:	Total: /

Comments:

LASER LEVEL CHANNEL CROSS-SECTION

Date: ____________________ **Site Visit Code:** ____________________

Waterbody: ____________________ **Station ID:** ____________________

Personnel: ______________________________

Station Distance (m)	Back-Sight (m)	Height of Instrument (m)	Fore-Sight (m)	Notation *(e.g.: Lbkf, LWE, THWG, RWE, Rbkf)

* Notations: Lbkf: Left bankfull, Rbkf: Right bankfull, LWE: Left Water Edge, RWE: Right Water Edge, THWG:Thalweg

STREAM CLASSIFICATION

Date:_____ Site Visit Code:_____

Waterbody:_____ Station ID:_____

Personnel:_____

Bankfull Width (W_{bkf}) m.

WIDTH of the stream channel, at bankfull stage elevation, in a riffle section

Mean DEPTH (d_{bkf}) _____ m.

Mean DEPTH of the stream channel cross-section, at bankfull stage elevation, in a riffle section.

_____ Sq. m

AREA of the stream channel cross-section, at bankfull stage elevation, in a riffle section.

Width/Depth RATIO (W_{bkf} / d_{bkf}) _____ m.

Bankfull WIDTH divided by bankfull mean DEPTH, in a riffle section.

Maximum DEPTH (d_{mbkf}) _____ m.

Maximum depth of the bankfull channel cross-section, or distance between the bankfull stage and thalweg elevations, in a riffle section

WIDTH of Flood-Prone Area (W_{fpa}) _____ m.

Twice maximum DEPTH, or ($2 \times d_{mbkf}$) = the stage/elevation at which flood-prone area

Entrenchment Ratio (ER) _____ m.

The ratio of flood-prone area WIDTH divided by bankfull channel WIDTH. (W_{fpa} / W_{bkf})

Water Surface SLOPE (S) _____ m/m.

Channel slope = "rise" over "run" for a reach approximately 20-30 bankfull channel widths in length, with the "riffle to riffle" water surface slope representing the gradient at bankfull stage.

Channel SINUOSITY (K) _____

Sinuosity is an index of channel pattern, determined from a ratio of stream length divided by valley length (SL/VL); or estimated from a ratio of valley slope divided by channel slope (VS/S).

Stream Type _____

Comments: